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Weed Community Changes Following Diuron, Simazine, or Terbacil Application[1]

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Abstract: Diuron, simazine, and terbacil were applied together or separately in the field each May from 1981 through 1996. Weed control was over 90% in 1981 and 1982, but by 1984 weeds increased in plots treated with diuron and simazine. Weed abundance was relatively low from 1981 through 1996 in plots treated with terbacil. Broadleaf and grass species abundance was similar in most herbicide-treated plots from 1992 through 1996. Perennial species, particularly fescue (*Festuca arundinacea*) and ailanthus (*Ailanthus altissima*), dominated sites treated with diuron and simazine. The weed community changed within 3 yr of the implementation of the weed management program that relied solely on herbicides. A relatively stable weed community persisted from 1992 through 1996. Repeated use of the combined high rate of diuron and low rate of terbacil provided excellent weed control for 15 yr.

Nomenclature: Diuron, *N'*-(3,4-dichlorophenyl)-*N,N*-dimethylurea; simazine, 6-chloro-*N,N'*-diethyl-1,3,5-triazine-2,4-diamine; terbacil, 5-chloro-3-(1,1-dimethylethyl)-6-methyl-2,4(1*H*,3*H*)-pyrimidinedione; ailanthus, *Ailanthus altissima* (Mill.) Swingle. #[3] AILAL; tall fescue, *Festuca arundinacea* Schreb. # FESAR.

Additional index words: Fruit orchards, selection, weed shifts, cheat, poison ivy, johnsongrass, yellow foxtail.

INTRODUCTION

Herbicides such as diuron, simazine, and terbacil have been available for nearly 30 yr and have been applied repeatedly for weed control in fruit orchards. New weed problems, based on genetic resistance or ecological avoidance, can develop when a single herbicide is first applied over several years. Diuron application for 3 yr consecutively beneath established fruit trees increased populations of plantains (*Plantago major* L.) in Britain (Banwell 1972). Repeated use of simazine selected for a phenology of common groundsel (*Senecio vulgaris* L.) that was less susceptible to simazine (Holliday and Putwain 1980). In addition, genetic resistance of *S. vulgaris* increased when simazine was applied continuously for at least 5 yr. In young apple (*Malus sylvestris* Mill.) orchards, redroot pigweed (*Amaranthus retroflexus* L.) and barnyardgrass [*Echinochloa crusgalli* (L.) Beauv.] increased following applications of simazine for 3 yr (Mellenthin et al. 1966). In the same experiment, plantains (*Plantago* sp.) and smartweeds (*Polygonum* sp.) increased following applications of diuron. Few experiments have monitored changes in the weed community resulting from applications of a single herbicide or mixture of two herbicides over many years. Such conditions may occur with perennial fruit crops.

New weeds can be managed in annual crops with crop rotation, cultivation, and use of herbicides with dissimilar modes of action (Cussans 1976). However, weed management in fruit orchards cannot employ annual crop rotation and infrequently includes cultivation. Shifts in weed populations can occur when cultivation is discontinued and herbicides alone are used for weed control. Perennial weeds flourished within 2 yr of herbicide use without tillage, and 90% of the weed cover was dominated by four species or fewer (Triplett and Lytle 1972). Cussans (1976) also reported perennial weeds became prominent as cultivation decreased. Thus, qualitative and quantitative changes may occur in the weed community of a young fruit orchard when cultivation ceases and herbicides are applied repeatedly. New weed management strategies may be necessary when flora changes or herbicide-resistant species become prevalent.

The current research was designed to determine whether weed communities changed over selected periods when diuron, simazine, and terbacil were applied from 1981 to 1996. Vegetation was evaluated from 1981

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds,* Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

through 1986 and 1992 through 1996. The objectives were to (1) determine whether weed abundance and species richness were altered by repeated use of a single herbicide or a herbicide combination and (2) identify species and growth forms of weeds that become dominant following repeated applications of a single herbicide or herbicide combination.

MATERIALS AND METHODS

The experiment was conducted at the Appalachian Fruit Research Station in Jefferson County, WV, on Hagerstown silt loam (fine, mixed, mesic Typic Hapludalf). A randomized complete block design with four replications was used. Eighteen weed control treatments were assigned to two row plots (2 by 10 m) that were randomly selected in each block. Each row was 100 m long and a 2-m grass strip separated each treated row. The weed control treatments were applied to the same plots in May from 1981 through 1996. Prior to 1981, corn (*Zea mays* L) was grown on the site. Weed control treatments were diuron, simazine, or terbacil applied alone or with one of the other herbicides at 0, 2.2, or 4.4 kg/ha. Soil was not disturbed on herbicide-treated plots. Additional weed control treatments were soil cultivation in spring, fall, spring plus fall, and no cultivation (control). In the cultivated plots, soil was cultivated to 10 cm deep with a tractor-mounted rotary tiller. No crop was planted in any plot. All plots were mowed to 20 cm each February to remove tall shoots and to ensure uniform herbicide application in May.

Percent ground area covered by weeds was visually determined during July from 1981 through 1986. Dominant weeds—those prevalent in occupying space—were recorded, but individual species abundance was not estimated. Plots were again evaluated for percent ground covered by weeds from 1992 through 1996 in May prior to herbicide application and in September. Five 0.1-m^2 quadrats were placed within each plot and weed abundance was visually estimated as the percent ground area covered for total vegetation and for each species. Weeds were grouped as annual or perennial and broadleaf or grass to generally characterize the weed community and identify major changes in species abundance with time. The number of different weed species within a quadrat was used to estimate community richness.

Weed community species composition in 1992 and 1996 was compared for each weed control treatment. Community similarity coefficients (Sj) were calculated based on the formula

$$\mathrm{Sj} = a/(b + c - a),$$

where a is the number of species common to a plot in both 1992 and 1996, b is the total number of species in a plot in 1992, and c is the total number of species in a plot in 1996 (Jaccard 1912).

Individual species abundance from 1992 to 1996 are presented only where the percent ground covered by the weeds was at least 20% of the ground area covered during 1 yr or at least 10% of the ground area covered during 2 yr. Weed species covering less ground area were considered scarce and not a weed pest, although such species may be important to ecosystem function. Percent ground covered by weeds was lower in May than in September, but treatment effects were similar for both measurement dates each year. September data were used to characterize the weed communities in 1991 to 1996; both September and May data were used for community similarity analyses. The effects of year, weed control treatment, and their interaction on weed abundance and weed community characteristics were evaluated by ANOVA. Year was a repeated measure factor and the effects of year and of the year by weed control treatment interaction were tested with the error term of year by replication nested within weed control treatment. Effects of weed control treatment were tested with the error term of replication nested within weed control treatment. Linear and quadratic contrasts were used to characterize trends in community changes over time. Fisher's protected LSD was used to separate weed control effects within a specific year.

RESULTS AND DISCUSSION

Weed Abundance and Diversity. Percent ground covered by weeds changed with time and differed due to method of weed control (ANOVA not shown). However, interactions of weed control treatment and year were not significant for most weed community traits, including vegetation abundance, indicating that the relative efficacy of weed control treatments was consistent from one year to the next.

Weed control was excellent with all herbicides during the first 3 to 4 yr of the experiment (Table 1). Differences in herbicide effects became evident over time. Weed control decreased from 1984 through 1986 in plots treated with diuron and simazine. By 1986, the high rate of simazine applied with diuron gave better weed control than simazine or diuron alone. From 1992 through 1996, single or combined applications of diuron and simazine did not reduce weed abundance compared to control.

Table 1. Weed abundance measured in July from 1981 through 1986 and in September from 1992 through 1996 in plots treated with diuron, simazine, and terbacil from 1981 through 1996.

Herbicide			Time of cultivation	Ground area covered[a]											Trend over time[b]	
Diuron	Simazine	Terbacil		1981	1982	1983	1984	1985	1986	1992	1993	1994	1995	1996	1981–1986	1992–1996
				oz.												
2		0	None	10	5	8	24	55		68	88	82	86	80	L	ns
4		0	None	0	6	16	14	27		84	89	94	100	100	L	L
2		0	None	2	2	5	11	27		72	80	82	85	89	L	ns
4		0	None	0	3	0	7	30		68	70	69	77	85	L	ns
0		0	None	5	5	45	80	71		73	78	84	90	100	L	L
0		0	None	5	0	16	46	46		68	78	86	86	91	L	ns
2		0	None	0	0	0	1	4		95	98	92	90	91	L	ns
4		0	None	2	2	6	5	15		80	78	66	75	84	L	ns
0		2	None	0	2	28	9	12		15	27	37	43	39	ns	ns
2		2	None	2	0	3	1	5		11	29	19	39	45	ns	ns
4		2	None	0	0	0	0	0			1	3	5	4	ns	ns
0		2	None	2	1	3	2	2		12	18	22	32	30	ns	L
0		2	None	0		8	4	2		16	32	20	25	22	ns	ns
0		4	None	5	0	5	5	2			4	8	14	19	ns	ns
0		0	None	35	90	90	90	75		84	87	93	99	100		ns
0		0	Spring [S]	40	90	nm	90	45		63	68	77	91	88		L
0		0	Fall [F]	7	90	nm	nm	20		43	53	58	86	93		L
0		0	S + F	0	nm	nm	nm	7		74	81	93	91	99		ns
LSD (0.05)[c]				5	5	30	15	28		32	35	30	34	33		

[a] nm, not measured.

[b] L, linear change; ns, no change.

[c] Fisher's protected LSD to compare weed control treatments within each year and time of measurement.

Terbacil controlled weeds over more years than diuron or simazine. The best weed control was obtained with the combination of high diuron and low terbacil rates. Weed abundance in plots cultivated in spring or fall increased between 1992 and 1996 and generally did not differ from control (Table 1).

From 1992 through 1996, species richness increased in herbicide-treated plots measured in spring (Table 2). Species richness generally did not change in cultivated plots measured in spring or in any plot measured in fall. Community coefficients reflect the constancy of weed community species composition in 1992 and 1996. In general, the weed species changed more in terbacil-treated plots than in simazine- and diuron-treated plots. Weed density can increase with weeds that are tolerant of reduced tillage compared with mold-board-plowed treat-

Table 2. Total number of species, number of species in common, and community coefficients comparing vegetation in 1992 with 1996 as measured in spring and fall.

Herbicide			Time of cultivation	Fall species				Spring species			
Diuron	Simazine	Terbacil		1992	1996	In common	Community coefficient	1992	1996	In common	Community coefficient
				no.				no.			
		0	None	11	7	7	0.64	12	15	6	0.29
		0	None	12	6	5	0.38	16	21	10	0.37
		0	None	9	8	4	0.31	10	20	8	0.36
		0	None	8	6	5	0.56	13	15	7	0.33
		0	None	6	6	5	0.71	10	10	6	0.43
		0	None	7	8	7	0.88	5	15	5	0.33
		0	None	5	7	4	0.5	6	17	5	0.28
		0	None	8	8	6	0.6	7	18	5	0.25
		2	None	7	10	6	0.55	17	26	8	0.23
		2	None	7	8	3	0.25	6	18	4	0.2
		2	None	2	3	1	0.25	4	10	1	0.08
		2	None	5	8	3	0.3	6	18	4	0.2
		2	None	5	6	0	0.22	6	16	1	0.05
		4	None	2	3	2	0.67	2	12	1	0.08
		0	None	15	8	6	0.35	23	23	13	0.39
		0	Spring [S]	17	14	7	0.29	28	30	17	0.41
		0	Fall [F]	18	21	6	0.18	24	20	12	0.38
		0	S + F	19	7	5	0.24	23	23	12	0.35

ments (Ball and Miller 1993). In the current experiment, it was likely that species were tolerant of simazine and diuron treatment. However, weeds were not tested for resistance.

Dominant Species and Growth Forms. In 1981 and 1982 the most prevalent weeds were redroot pigweed, common lambsquarters (*Chenopodium album* L. # CHEAL), yellow foxtail [*Setaria glauca* (L.) Beauv. # SETLU], and poison ivy [*Toxicodendron radicans* (L.) Ktze. # TOXRA]. In 1985 the most prevalent weeds were white heath aster (*Aster pilosus* Willd. # ASTPI), yellow foxtail, and large crabgrass [*Digitaria sanguinalis* (L.) Scop. # DIGSA]. 'Kentucky 31' fescue (*Festuca arundinacea*) and ailanthus (*Ailanthus altissima*) were the most prevalent species from 1992 through 1996 in plots treated with diuron and simazine (Table 3). Johnsongrass [*Sorghum halepense* (L.) Pers. # SORHA] was the only weed present on more than 20% of the ground area in terbacil-treated plots (Table 3). Broadleaf and grass weeds were approximately equal and few annual species were present in herbicide-treated plots (Table 4). These results agree with Foy et al. (1994) that the herbicides controlled annual weed species but released perennial weed species. Triplett and Lytle (1972) suggested that perennial weed populations might increase by beginning growth in spring prior to herbicide applications when herbicide residues were low and when cultivation was no longer part of the weed management program. In the current experiment, it is likely that seed and vegetative propagules of the most common species grew, after diuron had degraded, and established roots that were deep enough such that diuron uptake from subsequent applications did not occur. Diuron degrades rapidly and generally does not leach in the soil (Patzold and Brummer 1997; Tworkoski et al. 2000).

Vegetation characteristics were similar between control and herbicide-treated plots that did not receive terbacil (Table 4). Terbacil-treated plots had broadleaf and perennial coverage that was similar to cultivated plots but less than control plots. Untreated control plots were dominated by Kentucky 31 fescue and ailanthus. Grass abundance was greater and perennial plants were less abundant in cultivated than control plots (Table 4). Yellow foxtail increased with time in fall-cultivated plots, and johnsongrass increased in spring-cultivated plots (Table 3). In plots cultivated in spring and fall, total ground cover by weeds did not change with time, and yellow foxtail and johnsongrass were prevalent (Tables 1 and 3). Although several foxtail species have resistance to atrazine (Wang and Dekker 1995), yellow foxtail was not prevalent in herbicide-treated plots in this experiment. Seed germination may have been reduced with yellow foxtail as with giant foxtail (*Setaria faberi* Herrm. # SETFA) because of reduced tillage (Mester and Buhler 1991). Giant foxtail populations decreased because seed germination and growth was low in the cool, deep, undisturbed soil.

Johnsongrass was nearly absent from fall-cultivated plots but was present in plots cultivated in both spring and spring plus fall. In May, cheat (*Bromus secalinus* L. # BROSE) was present only in fall-cultivated plots (data not shown). In a subsequent experiment, apple and peach [*Prunus persica* (L.) Batsch] trees were planted in all the plots of this experiment and growth inhibition of fruit trees was observed in only fall-cultivated plots. It is possible that allelopathic effects of cheat may have inhibited johnsongrass. Other species of brome have been allelopathic (Putnam and Weston 1986).

Herbicide Combinations. Application of two herbicides together usually did not affect weed control differently than application of a single herbicide (Table 1). Percent ground cover of broadleaf, perennial, and annual weeds was similar between diuron and simazine when applied alone or in combination (Table 4). Terbacil alone provided better weed control than diuron (Table 1). However, terbacil at the low rate plus diuron at the high rate provided the greatest reduction of percent ground covered by weeds of all weed control systems. Addition of either rate of simazine to the low rate of terbacil did not improve vegetation control or affect the abundance in any vegetation category.

Efficacy differed among diuron, simazine, and terbacil, and only terbacil maintained low weed abundance for the 15 yr of this experiment. Weeds that were most abundant on herbicide-treated plots were perennial plants that usually are deep-rooted and thus less likely to absorb the herbicides evaluated in this experiment. Morphological or phenological avoidance, rather than genetic resistance, most likely allowed survival of species such as ailanthus and tall fescue. Normal herbicide programs for fruit orchards sometimes include contact herbicides that kill ailanthus and tall fescue. Results from this experiment demonstrate that continuous use of diuron and simazine alone was not as effective as terbacil alone to manage weeds, perennial grass or broadleaf weeds became dominant across all herbicide treatments, and number of weed species increased with time in nearly all plots receiving herbicides. In orchards of the eastern U.S., repeated applications of diuron, simazine, and ter-

Table 3. Abundance of weed species that covered at least 20% of the ground during September for at least 1 yr. Abundance was measured from 1992 through 1996 in plots treated with combinations of diuron, simazine, and terbacil from 1981 through 1996.

				Ground area covered																							
				Kentucky 31 fescue						Yellow foxtail						Ailanthus						Johnsongrass					
Herbicide			Time of						Trend						Trend						Trend						Trend
Diuron	Simazine	Terbacil	cultivation	1992	1993	1994	1995	1996	over time[a]	1992	1993	1994	1995	1996	over time	1992	1993	1994	1995	1996	over time	1992	1993	1994	1995	1996	over time
	kg/ha																										
																		%						%			
2	0	0	None	33	44	48	43	36	ns	1	0	0	0	0	ns	28	35	32	33	35	ns	2	1	1	1	1	ns
4	0	0	None	21	27	25	29	26	ns	0	0	0	0	0	ns	27	35	35	46	63	ns	14	6	1	5	0	ns
2	2	0	None	42	30	51	49	31	ns	0	0	0	0	0	ns	24	44	46	54	56	ns	5	6	1	2	0	ns
4	2	0	None	29	27	31	42	35	ns	0	0	0	0	0	ns	16	25	16	22	52	ns	26	15	7	7	3	ns
0	2	0	None	29	20	49	57	39	ns	1	1	0	0	0	ns	18	20	24	28	56	ns	28	23	3	5	5	ns
0	4	0	None	45	51	54	50	43	ns	0	0	1	0	0	ns	26	23	30	31	30	ns	0	1	0	0	1	ns
2	4	0	None	7	6	12	16	17	ns	0	0	1	1	1	ns	89	65	65	68	75	ns	1	1	1	1		ns
4	4	0	None	5	5	10	19	31	ns	0	1	1	0	1	ns	18	24	41	38	38	ns	45	39	8	9	8	ns
0	0	2	None	0	4	4	4	0	ns	6	0	6	7	1	ns	0	1	9	5	1	ns	1	6	10	16	10	ns
2	0	2	None	1	0	5	10	0	ns	1	3	1	1	11	ns	6	6	5	10	0	ns	2	12	4	13	13	ns
4	0	2	None	0	0	0	0	0	ns	0	0	0	0	0	ns	0	0	0	0	0	ns	1	1	3	4	3	ns
0	2	2	None	0	0	0	0	0	ns	0	0	1	0	1	ns	0	0	0	6	16	ns	5	11	15	25	8	ns
0	4	2	None	0	0	0	0	0	ns	0	0	2	2	1	ns	0	0	0	0	0	ns	14	25	13	17	13	ns
0	0	4	None	0	0	0	0	0	ns	0	0	2	11	19	L	0	0	0	0	0	ns	0	0	0	0	0	ns
0	0	0	None	40	30	31	42	13	ns	1	0	0	0	0	ns	26	34	39	40	69	ns	0	0	0	1	0	ns
0	0	0	Spring [S]	0	0	0	2	0	ns	26	34	29	12	22	ns	1	1	1	1	1	ns	28	19	45	76	58	L
0	0	0	Fall [F]	6	0	1	3	38	ns	22	22	44	69	34	LC	0	1	1	1	1	ns	0	2	0	1	1	ns
0	0	0	S + F	0	0	0	0	0	ns	55	20	56	32	88	Q	1	1	1	0	0	ns	10	52	36	47	11	ns
LSD (0.05)				26	27	25	28	32		15	17	17	11	15		27	39	35	36	45		28	35	20	24	18	

[a] ns, L, Q, and C designate no, linear, quadratic, or cubic change with time, respectively.

Table 4. Vegetation abundance categorized by growth form and life cycle of seedling weed species measured in September from 1992 through 1996 in plots treated with combinations of diuron, simazine, and terbacil from 1981 through 1996.

Herbicide				Ground area covered[a]																					
				Broadleaf						Grass						Annual						Perennial					
Diuron	Simazine	Terbacil	Time of cultivation	1992	1993	1994	1995	1996	Trend over time[b]	1992	1993	1994	1995	1996	Trend over time	1992	1993	1994	1995	1996	Trend over time	1992	1993	1994	1995	1996	Trend over time
	kg ai/ha			%						%						%						%					
2	0	0	None	35	69	52	64	70	ns	35	44	48	43	37	ns	1	1	1	0	0	ns	70	113	100	107	107	ns
4	0	0	None	58	67	84	80	90	ns	35	33	26	35	26	ns	1	1	1	0	0	ns	92	100	109	115	116	ns
2	2	0	None	38	53	54	59	75	ns	47	36	52	51	31	ns	1	0	1	0	0	ns	84	89	105	110	106	ns
4	2	0	None	21	38	34	38	69	ns	55	42	37	49	37	ns	1	2	1	0	0	ns	75	79	71	86	106	ns
0	2	0	None	30	44	42	43	68	L	57	44	52	62	44	ns	1	1	0	0	0	ns	86	88	94	105	112	ns
0	4	0	None	36	51	55	64	65	ns	45	51	54	50	43	ns	0	1	1	0	0	ns	81	102	109	114	108	ns
2	4	0	None	92	97	92	95	88	ns	8	6	13	16	17	ns	0	0	1	1	1	ns	100	103	104	111	104	ns
4	4	0	None	40	57	78	60	56	ns	49	44	18	29	39	ns	1	1	1	0	1	ns	89	101	96	88	95	ns
0	0	2	None	8	13	22	24	29	ns	7	13	20	27	11	ns	9	7	8	8	1	ns	6	19	34	43	38	ns
2	0	2	None	9	19	12	21	20	ns	2	12	9	23	25	ns	1	5	1	4	18	ns	11	26	20	41	27	ns
4	0	2	None	1	1	1	1	2	ns	1	1	3	4	3	ns	0	0	0	0	0	ns	1	1	3	5	4	ns
0	2	2	None	1	8	4	10	23	ns	6	11	20	25	8	ns	1	2	1	2	3	ns	6	17	22	33	28	ns
0	4	2	None	2	10	5	7	10	ns	14	25	15	19	13	ns	2	7	2	2	9	ns	14	28	19	23	13	ns
0	0	4	None	2	4	6	3	1	ns	0	0	2	11	19	L	1	4	5	13	19	ns	1	1	3	2	1	ns
0	0	0	None	63	84	90	87	96	ns	40	30	35	42	13	ns	3	1	1	0	0	ns	101	114	124	129	109	ns
0	0	0	Spring [S]	8	9	6	8	7	ns	55	63	75	90	81	L	30	48	34	16	26	ns	33	23	47	82	82	LC
0	0	0	Fall [F]	12	16	12	8	22	ns	31	43	48	84	72	L	30	26	55	86	35	LQC	12	33	5	5	58	LQC
0	0	0	S + F	5	9	6	16	1	ns	66	76	92	79	100	ns	59	31	60	47	89	LQ	12	54	38	47	12	Q
LSD (0.05)[c]				31	42	46	41	53		35	38	32	34	36		16	17	16	9	19		34	48	46	44	43	

[a] Sum of percent ground area covered by individual species within each category. In some cases values exceed 100% due to a multilayered canopy.

[b] Trends over time were not statistically evaluated in May because growth stage was not uniform for each year. The symbols ns, L, Q, and C designate no, linear, quadratic, or cubic change with time, respectively.

[c] Fisher's protected LSD to compare weed control treatments within each year and time of measurement.

bacil will not uniformly control weeds. Over time, terbacil controlled weeds better than diuron or simazine.

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